On the distinction of pollen grains of early varieties of *Hordeum* from *Glyceria* species: addressing the early cereal cultivation problem in palynology

Bruce M. Albert*

Department of Archaeology, University of Durham, South Road, Durham DH1 3LE

James B. Innes

Geography Department, University of Durham, South Road, Durham DH1 3LE

Abstract

Pollen grains of primitive varieties of *Hordeum vulgare* collected by the Gene bank of the Crop Research Institute, Prague are compared to pollen of native *Glyceria* species of the United Kingdom with a view to establishing separation criteria. It is found that a separation of *Hordeum vulgare* from both *Glyceria maxima* and *Glyceria fluitans* is possible according to annular characteristics in combination with grain size as dependent variables. These findings have implications for the identification of cereal-type pollen grains which could be evidence for early cultivation in the Terminal Mesolithic of north-west Europe, and for the use of palynology as a reliable source of palaeobotanical data, particularly in its inland areas. A phase of vegetation disturbance from the pollen site of Dog Hill in the southern Pennine uplands of the UK, an area with a high density of 'rod' microlith flint sites, is introduced as a case example using the above protocol. Here multiple *Hordeum*-type grains are encountered alongside prominent pollen indicators of disturbance, but also including non-pollen palynomorphs and microcharcoal data, at a date well before the mid-Holocene decline in *Ulmus* pollen frequencies which is often regarded as marking the beginning of the Neolithic. Secure identification of cereal-type pollen will greatly assist the understanding of the introduction of cultivation and the Mesolithic-Neolithic transition in north-west Europe.

Keywords: Early cultivation, *Glyceria maxima, Glyceria fluitans, Hordeum vulgare,* pollen morphology, rod microlith sites

* Corresponding author Email: b.m.albert@durham.ac.uk

1.1. Introduction

The establishment of farming represents one of the fundamental developments of human society. Research into this process uses different sources including archaeology and archaeo-botany, and within the latter sphere of inquiry, an informed application of palynological methodology may also be important with a view to identifying early cereal cultivation. Such efforts are often limited by the overlap in pollen morphology of wild versus cultivated grass species (Andersen, 1979), although the relative likelihood of cereal cultivation may be increased through the cereal-type pollen grains' association with elements of the palynological assemblage such as a weed flora that can occur under a farming land-use system, as well as microscopic charcoal (Innes et al. 2006, 2013). Even with associated disturbance evidence, confidence in the results of such pollen identifications (e.g. Ryan and Blackford 2009; 2010) may be limited in some regions due to the presence of known wild Poaceae species whose pollen is difficult to distinguish from that of cereals (Dickson 1988; Tweddle et al. 2005, Behre 2007, Joly et al. 2007). Such regions are diverse in character, and include the southern United States (Eubanks, 1997) in the New World, and in the Old World, Maritime Europe (Hall et al. 1993) as well as inland areas of Europe like the upland UK where two native *Glyceria* species (*G. maxima* and *G. fluitans*) occur (Lambert 1947; Rodwell 1991, 1995). Both of these species of sweet-grass require standing water of pools, ponds or ditches with *G. fluitans* preferring an aquatic margin habitat, and are indicative of reedswamp and fen communities (Rodwell 1995). Because of its edaphic requirements *G. maxima* is generally a plant of lowland, eutrophic habitats. *G. fluitans* is more likely to be present in more mesotrophic or acidic bog pool and poor fen wetlands in the uplands, although is never likely to have been common in such habitats (Rodwell 1991). *Glyceria* is the sole genus of native Poaceae that inhabits non-coastal biomes of the British Isles whose pollen may be confused with cereal-type pollen, particularly with that of *Hordeum* (barley). It is therefore considered here as the major complicating factor in the identification of cereal-type pollen on pollen diagrams from inland Britain, and is the focus of this paper.

In this study, based on an analysis of primary (i.e. contemporary) pollen material, the pollen morphology of a primitive variety of *Hordeum vulgare* is compared to that of native UK wetland grass species *Glyceria maxima* and *G. fluitans*, with the aim of elucidating the palynology of the early farming transition which began around 6000 cal. yr BP in the British Isles (Williams 1989). This transition to Neolithic farming cultures and economies is a critical phase of culture change that is of particular interest to archaeologists (Armit et al. 2003), but the character of the farming transition, and especially the mode of transfer of cultigens to new environments and the role of specific cultures in this transition, remains an unresolved problem (Whittle 2007, Thomas 2007). As a case example, in this study we examine pollen spectra from a well-defined cultivation phase of Mesolithic-Neolithic transition age at the site of Dog Hill on Rishworth Moor in the southern Pennine hills of the UK (Fig.1), which was found to contain several cereal-type (*Hordeum*) pollen grains. This pollen site is situated close to several archaeological 'rod microlith' flint sites regarded as of 'Terminal Mesolithic' typology (Spikins 2002). Although these Rishworth Moor 'rod' sites are undated, this class of flint site dates tightly (Switsur and Jacobi 1975; Griffiths 2014) to the period 5000 to 5800 uncalibrated radiocarbon years BP (^{14}C BP), approximately 5700 to 6600 cal. yr BP, corresponding, in its later part at least, to the time of the Mesolithic/Neolithic transition in northern England. These 'terminal Mesolithic' microlithic flint sites are clearly distinct in material culture from Early Neolithic archaeological assemblages, although some artefacts of Neolithic type, such as leaf-shaped arrowheads, are occasionally found on such very late Mesolithic sites (Young 1990) and may suggest an element of continuity in their use. Given their context within the Mesolithic-Neolithic transition, it is likely that palaeoecological evidence at such sites can significantly augment the present understanding of the nature of the transition to farming in northern England, and potentially in the British Isles as a whole. Using Dog Hill as a case study, identification of the type of land use associated with such sites might provide evidence to test whether cereal cultivation was being carried on in these upland areas during the Mesolithic-Neolithic transition. If cereal-type pollen grains can be found and can be securely identified, it would elucidate the cultural

status of these ‘Terminal Mesolithic’ flint sites, hitherto presumed to be the location of hunter-gatherer activity. At Dog Hill the particular attributes of all *Hordeum*-type grains have been carefully recorded, including the long-diameter measurements of both them and of all encountered Poaceae (grass family). All such fossil pollen grains have been assessed by comparison with the morphology of the primary (i.e. herbarium and field collection) pollen material reported here. This Poaceae morphological database allows an assessment of the possible presence of large wild grass pollen grains in the fossil samples, with special reference to the two native UK *Glyceria* species and the *Hordeum*-type. We have observed that most Poaceae pollen spectra, where possible ‘pseudo-cereal’ or cereal-type grains are not present, exhibit a logarithmic decrease in grains above 28 μm in size as a proportion of grass pollen. Above this threshold, different *Glyceria* species as well as *Hordeum* may exhibit peak values that can be detected statistically as skews in the Poaceae pollen sum. A protocol for barley pollen identification can therefore be implemented (Albert and Innes 2015). In the levels containing *Hordeum* pollen, weed flora (ruderal herbs), coprophilous fungal spores (non-pollen palynomorphs, hereafter termed NPPs) and microcharcoal frequencies all help to define the ecology of this early farming land use.

Despite its limitations, therefore, the palynological method has the advantage that it may be used to define the full ecological context of early farming, and can stimulate debate on what can be a controversial subject (Behre 2007; Tinner et al. 2007). Thus unusually early cereal-type pollen identified in Maritime Europe, at Vertonne in the Armorica region of France (Joly and Visset 2009), although perhaps belonging to halophytic grasses of the taxa discussed by Hall et al. (1993), might also relate to early farming traces given associated disturbance taxa. It is noted that Joly et al. (2007) produced a major work on comparative morphology of wild versus cultivated types based on glycerol pollen preparations, and has identified major vegetation disturbance in these same Cerealia-type spectra from Vertonne and other Armorica sites. However, such identifications might not be accepted readily by archaeologists, and in the case of the Armorica sites, early cereal types pre-date initial Neolithic, Linienbandkeramik, sites in northeastern France by approximately 1000 years.

At face value, acceptance of such cultivation would require also a use of cultivated plants by hunter-gatherers of maritime Europe prior to the onset of the Neolithic proper. Problems of identification of early cereal cultivation are significantly reduced, however, where the number of wild Poaceae taxa producing large pollen grains is low, making inland regions with low floral diversity ideal for examining early farming practise. In this work, just such a region is examined in the southern Pennines of the UK. Importantly, pollen preparations here are made differently from Joly et al. (2007) and involve a silicone oil matrix that eliminates problems of grain expansion experienced in glycerol (Faegri et al. 1989). This is critically important for taxonomic distinctions based on various size characteristics. It follows that for a secure use of palynology in the definition of early farming episodes, it is critical to define the relative frequency of expression of isomorphic characteristics *vis a vis* the pollen grains of early cereal varieties, even where absolute distinctions are not possible. These early varieties would of course be those used by either transitional Mesolithic farmers (native adoption mode) or Early Neolithic immigrant farmers (migrant dispersal mode). A better archaeological understanding of the mode of the spread of farming is thus significantly advanced by such study. In summary, this work will attempt to define

1. A morphological overlap factor, in terms of proportion of problematic, ambiguous pollen grains, of two modern native UK *Glyceria* species collected in northern England and a primitive variety of winter barley (*Hordeum vulgare*) obtained from the Gene Bank of the Crop Research Institute, Prague. This will be done using silicone oil as the mounting medium on microscope slides.
2. The comparability to the above primary database of a *Hordeum*-type pollen assemblage from a major cultivation phase in Mesolithic-Neolithic transition sediments at the site of Dog Hill in upland northern England.
3. Implications of the dating of the Dog Hill assemblage and the proximity of ‘Terminal Mesolithic’ archaeological sites for the establishment of modes of the first cultivation in the English uplands.

1.2. Ecology and timing of the Neolithic transition in Britain and Ireland

Palynology has played an important role in defining the character of the Neolithic farming regime in both Britain and Ireland (Woodman 2000; O'Connell and Malloy 2001; Tipping et al. 2009; Woodbridge et al. 2014). In lowland areas the pollen record can include evidence of significant woodland clearance (reflected in high Poaceae, which can exceed 30% of TLP) and a widespread appearance of anemophilous weed taxa like *Plantago lanceolata* and Chenopodiaceae, along with cereal pollen. In the earlier Neolithic, however, the farming impact is generally lower scale, even at the Elm Decline (Smith and Pilcher 1973; Parker et al. 2002) by which time the cultural Neolithic must have been well established. This low-scale Neolithic impact matches the pollen evidence from north-western Europe in cultures such as the Linienbandkeramik, where usually only small clearings are encountered (e.g. Bakkels 1992; Out 2008). In both western Europe and the British Isles, however, there are very early records of cereal pollen type which pre-date the local Elm Decline by as much as several centuries (Edwards and Hirons 1984; Edwards 1989; Innes et al 2003b) and which, if really of cereal origin, are evidence for the very early introduction of cereal cultivation as one of the first elements of the Neolithic 'package' of novel food production techniques. If so, whether by pioneer Neolithic immigrants to the British Isles or by very late Mesolithic foragers with trade links to Neolithic populations must remain conjectural. Several early cereal-type pollen examples occur around c. 5800 ^{14}C BP, for example at Ballynagilly in County Tyrone, Northern Ireland (Pilcher and Smith 1979) but have provoked scepticism, particularly from archaeologists, as to the reliability of the cereal pollen identification. Interestingly, at Ballynagilly the cereal-type pollen is identified along with the cultivation weed Chenopodiaceae in stratigraphically adjacent samples, and an adjacent Neolithic archaeological site has several very early radiocarbon dates, including one of 5745±90 ^{14}C BP (Pilcher and Smith 1979) which is indistinguishable from the early cereal pollen date. In the Pennine Hills of northern England, cereal-type pollen has also been identified from the identical time period at Black Heath (just after 5777±37 ^{14}C BP, Ryan and Blackford 2009), and at Soyland Moor (5820±95, Williams 1985) both not far from the Dog Hill case example to be discussed below. Archaeological work on the Early Neolithic transition, in the UK in

particular, has focussed principally on mortuary sites (cf. Whittle, 2007) where cereals were presumably much less likely to occur. Early Neolithic domestic settlement sites, where cereals would have been much more likely to be present, have been more difficult to find and therefore have been examined archaeologically more rarely. The relatively few settlement sites that have been studied have been promising with regard to indications of cultivation, with strong evidence for the storage of cereals (Jones 2000). Good examples include Lismore Fields in Derbyshire (Garton 1991) and Billown in the Isle of Man (Darvill 2003). It is interesting that both of these settlement sites are not far from palaeoecological sites where evidence of early cereal-type pollen has been forthcoming (Wiltshire and Edwards 1993; Innes et al. 2003a, b). These sites also preserve some evidence of Mesolithic-Neolithic archaeological continuity, as do many sites, such as the Fir Tree shaft at Down Farm in southern England (Green and Allen 1997; Griffiths 2014) where, significantly, rod microliths have been dated to very late in the Mesolithic-Neolithic transition.

Hordeum is known from palaeobotanical evidence to have been a cereal grown in north-west Europe in early Neolithic times (Bakels 1992). From the perspective of macro-botanical work in the British Isles, Neolithic assemblages in Ireland comprise a mixture of emmer wheat (*Triticum diococcum*), barley (*Hordeum vulgare*) and occasionally, flax (*Linum ussitassimum*), while common weeds include *Plantago lanceolata*, *Chenopodium album* and *Galium aparine* (McClatchie et al. 2014). Of these taxa, only *Plantago lanceolata* and *Chenopodium album* exhibit a profuse and anemophilous pollen production, and regularly appear in pollen diagrams at a significant remove from settlements (cf. Behre and Kučan 1986), and they are prominent during post-Elm Decline cultivation episodes in published diagrams from lowland peats in Ireland (O'Connell and Malloy 2001). In northern England (Hall and Huntley 2007), plant macrofossil assemblages of Neolithic age include *Corylus avellana* (e.g., Caythorpe, Yorkshire), *Linum* (e.g. Nosterfield, Yorkshire), as well as prominent *Triticum diococcum* and *Hordeum vulgare* (the latter especially at Brandesburton, East Yorkshire). Domesticated livestock represent a further element in the Neolithic economy, with faunal remains of domesticated *Bos* dating to the pre-

and early Neolithic (5510±70 and 5825±50 ^{14}C yr BP) at Ferriters Cove in County Kerry, Ireland (Woodman 2000), the earliest well established find for domesticated cattle in the British Isles. Intensive grazing or browsing by such livestock, in addition to wild fauna, may also be discerned in pollen diagrams (López-Sáez and López-Merino, 2007; Cugny et al. 2010) through fungal spores like *Cercophora* (HdV-112), *Sporormiella* (HdV-113) and *Podospora* (HdV-368). Species of these genera generally indicate a presence of animal dung, and m*any Podospora* species were first identified in cattle dung, particularly.

A major limitation in the understanding of the dynamics of the transition to farming in the British Isles lies, however, in the narrow range of preservation of materials at Late Mesolithic sites, particularly in upland areas (generally, above 300 m) where many such sites are located (Mellars 1976; Smith 1992). In terms of material culture, such sites are generally defined almost exclusively according to their microlithic stone tool assemblages, with little or no preserved faunal or floral materials in close association. Here palynology can play a critical role especially in the definition of Late Mesolithic land use and economy. A large database from several regions of upland Britain (e.g. Jacobi et al. 1976; Simmons and Innes 1987; Tallis and Switsur 1990; Simmons 1996; Innes and Simmons 2000; Blackford et al. 2006; Innes et al. 2013) indicates widespread fire disturbance of woodlands, with the encouragement of animal grazing, browsing and presumed human exploitation of increased faunal biomass, a type of managed economy (Jacobi et al. 1976). Vegetable foods, such as hazelnuts, would also have been increased in abundance for human exploitation (Regnell 2012). Towards the end of the Mesolithic, the land-use economy may have involved increased elements of food production, so that flint implements such as rod microliths, typically less than 2 cm in length, that are thought to have been mainly hafted as projectile armatures, might also have been used in composite agricultural tools like scythes. For example, palynological investigations in close proximity to a rod microlith site at Esklets in the North Yorkshire Moors (Albert and Innes 2015), produced two pollen grains of *Hordeum*-type in peat dating to c 6000 cal. yr BP, in the latter stages of the Mesolithic-Neolithic transition.

2. Methods and materials

The question of distinguishing the pollen of early cereals from wild grasses has been a subject of considerable and often heated debate in the case of the transition to farming in Europe (Behre 2007; Tinner et al., 2007), which is represented archaeologically by the change from Mesolithic to Neolithic material culture. Major problems remain as to the morphological distinction between grass pollen grains produced by some wild taxa and those from the types of early cereals that would have been cultivated by Neolithic farmers (Edwards and Hirons 1984; Tweddle et al. 2005). Of course, this applies as much after the mid-Holocene Elm Decline in the British Isles (Parker et al. 2002) which is often regarded as a benchmark for the early Neolithic, as before it. Logically, cereal-type pollen grains in Neolithic and even later periods are just as equivocal as those found in pre-Elm Decline contexts, as wild grasses that can produce pollen grains that resemble those of cereals will still have been present in the landscape. It is therefore necessary to critically re-examine the morphological distinction of pollen grains of cultivated cereals and of wild grasses with a view to the specific traits or features that can establish clearer boundaries between them, and which do not rely on sometimes ambiguous micro-morphological aspects (Köhler 1979; Joly et al., 2007).

Technical limits on distinguishing early cereal cultigen pollen also depend upon laboratory methods, and a c. 10% pollen grain diameter expansion under glycerol preparations can distort size relationships such as the ratio of mean grain and annulus (outer pore) diameters, as measured by Andersen (1979), who used silicone oil preparations in a thorough review of Poaceae. For example silicone data indicate a significantly larger annulus (outer pore) diameter for some *Glyceria* species relative to *Hordeum* that is less apparent in glycerol data (cf. Beug, 2004; Joly et al. 2007). Interestingly, with respect to old glycerol preparations of the Poaceae on file at Władysław Szafer Institute of Botany in Kraków (as in *Glyceria maxima* produced at Brno, Czechoslovakia in 1965), grain expansion over many decades in glycerol may exceed 40%, although annular diameters appear to be less distinctly influenced.

Indeed published silicone oil data (Andersen 1979) as well as the first author's observation at the Władysław Szafer Institute, reveal that some *Glyceria* grains have an annular diameter significantly exceeding that of *Hordeum vulgare*, while *Glyceria* grains with smaller annular diameters are also often smaller as to grain diameter. European *Glyceria* species with large outer annuli include *G. aquatica* and *G. declinata*, not native to the British Isles.

To obtain systematic, detailed measurements of pollen grain morphology modern samples of UK *Glyceria* species (G. *fluitans, G. maxima*) were obtained from John Durkin, County Durham recorder for the Botanical Society of the British Isles, from Shibdon Pond in the Tyne Valley in northeast England. Also obtained were primitive varieties of *Hordeum vulgare*, collected from the Gene Bank of the Crop Research Institute, Prague, Czech Republic (accession numbers 01 CO 502100 and 01 CO 502101, (which originated from winter barley in northwest Turkey). The pollen of both was mounted in silicone oil (to prevent grain expansion) after laboratory preparation using acetolysis. Microscope slides were analyzed under x1000 magnification (anisol) with a binocular light microscope. Morphologically, the pollen from these modern primitive varieties of *Hordeum* will be that most closely related to the initial, mid-Holocene barley cultigen pollen from the UK. In the case of the *Glyceria* species from Shibdon Pond, flowering elements have been used for sample preparation to recover pollen. Barley cereal corn (~10 cc volume) was used in the case of modern *Hordeum* accessions 01 CO 502100 and 01 CO 502101. Annular diameters as well as grain size diameters have been measured as an average of long and short diameters in each case (50 measurements per species, each measurement significant to 0.5 microns). Annular rise (from outer grain surface) is also measured from cross-sectional observation of each individual grain (also significant to 0.5 microns) as a possible distinguishing element.

A primary aim here is to determine the encounter rate of *Glyceria* grains of a diameter above the threshold used for cereal identification under silicone oil (38 microns) as well as annular characteristics associated with problematic grains of that type, as

averaged data of Andersen (1979) suggest that it may be possible to separate *Hordeum* and *Glyceria* in UK contexts based on large annular diameters of the latter genus, which comprises only wild species. This comparative exercise is potentially valuable from the perspective of identifying barley cultivation in sediments from UK uplands where only two species are *Glyceria* are encountered today, and then not commonly, and coastal grasses of problematic morphology (genera *Elymus* and *Spartina*) are absent. The encounter rate of both problematic mean grain size and problematic annular characteristics will be estimated. It is important to note here that Andersen (1979) did not consider these aspects separately in his general review of Poaceae.

A secondary aim involves distinctions of micro-sculpturing (scabbrae), which is visually assessed in each recorded pollen grain (such elements comprise a central element of pollen keys oriented upon distinguishing Cerealia, e.g., Faegri et al. (1989). The scabbrate micro-sculpturing morphology common to both *Glyceria* and *Hordeum*, it should be noted, is in fact relative, depending on the clustering of columella elements, and some variability between grains is noticed in a visual assessment of all *Glyceria* and *Hordeum* (as well as other cereal) type-slides in the Władysław Szafer Institute of Botany collection. The proximity of such elements determines the expression of distinctive scabbrae under phase contrast (x1000 magnification) as well as direct light. In some cases, it is notable that certain *Triticum* species like *T. diococcum* (emmer) may also approach a scabbrate micro-morphology, but this is not encountered in hexaploid wheat species like *T. spelta* that more regularly type as *Triticum* as to surficial micro-sculpturing. Since some variation in the clustering of columella in individual grains may vary, this exercise will also assess the relative reliability of established keys, often derived from glycerol preparations (e.g., Beug 2004), relative to silicone oil ones. In particular, the spacing of columella may be altered by grain expansion under glycerol, with a different micro-sculpturing expression under silicone oil.

The site chosen as a case study to provide fossil pollen grains of *Hordeum*-type during the Mesolithic-Neolithic Transition is at Dog Hill (423 metres above sea level at UK grid reference SE 001171) on Rishworth Moor in the South Pennine uplands of northern England. A high altitude inland site was chosen to avoid complications from coastal grass species, and the two *Glyceria* species are much less common in acidic upland mires than in more mesotrophic lowland wetlands, increasing the likelihood that the fossil *Hordeum* type grains recorded there will originate from cultivated rather than wild grasses. The blanket peat at this location was first palynologically investigated by Bartley (1975) who recorded an early Elm Decline of c. 5400 ^{14}C BP, albeit with a large standard deviation, some centuries earlier than the average for the area. These blanket peats are heavily eroded, but contain palaeo-gullies and channels with deeper sediments, like those investigated by Bartley and by the current study. The location is also interesting for a major settlement focus (5 sites, see Fig. 1) of the Late Mesolithic rod microlith type, while evidence for Neolithic farming is very sparse (consisting of a single ground stone axehead). The peats probed at Dog Hill derive from a south facing drainage gulley and have been sampled continuously from the base to the Elm Decline at 5 mm (0.5 cm) intervals. A sequence from a pre-Elm Decline cultivation episode is presented here. Pollen samples from this were prepared from 1 cc peat volumes, using HCL, KOH and acetolysis, being mounted in a silicone oil matrix and examined at x400 (scanning) and x1000 (all larger Poaceae, in anisol) magnification. Seven samples of peat from the core have been dated by AMS, of which the two relevant to this study are presented here.

3.1. Results (contemporary pollen material)

In primary, Gene Bank material of *Hordeum vulgare*, an annular rise is observed in 42% of cases (21) and the average from the outer exine surface approximates 1.5 μm, with a standard deviation of 0.4 μm. On the exine surface, scabbrae are well defined in 88% of cases and importantly, the average annular diameter is 8.1 μm. In two cases (#s 45, 47), this averaged measurement is 9 μm or larger. Importantly, these are also the largest grains encountered (49 and 47 μm respective long-diameters), so that long-diameter to outer annular diameter is approximately 5:1. In a

small number of cases (#s 17, 19, 47), grains of ‘cereal size’ (below) have diameter to outer annular diameter ratios that are less than 5:1. In these cases, outer annular diameters are just under 9 µm (~8.75 µm). Long diameters average 39.6 µm (standard deviation 3.8 µm) and attain a value of less than 38.0 µm in 26% of cases. About one quarter of *Hordeum vulgare* (winter variety) will not type-out as cereals under this standard, although surface sculpture is reliably identified in 88% of cases. Since scabbrae are defined based upon columella element clustering, this may also be negatively correlated in the case of large grains. Thus all indeterminate grains with respect to scabbrae are also all large and type-able as cereals, and include also the largest grain encountered (# 40).

In primary material of *Glyceria maxima* from Shibdon Pond, an annular rise is observed in 38% of cases. The average annular diameter here is 6.6 µm (standard deviation 0.8 µm). Importantly, no grains of ‘cereal size’ are encountered and long diameters average 32.5 µm (standard deviation 3.0 µm). Scabbrae are well defined in 74% of cases. According to size (long-diameter) parameters, *Glyceria maxima* is thus not a problematic type, it is quite similar if not isometric to smaller *Hordeum vulgare* grains that do not type-out as cereals in established keys.

Interestingly, *Glyceria fluitans* pollen grains from Shibdon Pond express different characteristics. In *G. fluitans* an annular rise is small (average 1.2 µm, with a standard deviation of 0.5 µm) and observed in only 21% of cases. Most important is the regularly very large average annular diameter here (9.6 µm, standard deviation only 0.5 µm). This affirms observations of Andersen (1979), and this average value suggests a potential threshold for separation from *Hordeum vulgare*. Importantly, 30% of *Glyceria fluitans* grains are of cereal-size. Thus, all grains of ‘cereal size’ have an annular diameter larger than 9.0 µm (9.8 µm, standard deviation only 0.4 µm). This indicates that an annular diameter larger than 9.0 µm, and an outer annular to long-diameter ratio of ~4:1 or less will exclude *Hordeum vulgare*. Notably also, scabbrae are well defined in 100% of cases, in other words, somewhat better defined *vis a vis* the latter case.

3.2. Results (Dog Hill)

According to the protocol described above, a total of 14 *Hordeum*-type grains, ranging in diameter from 38 to 41 μm were encountered at Dog Hill, the latter beyond the size range normally encountered in *Glyceria fluitans*, with a nearly rational representation during the period shown in Fig. 2. Measurements are described in Table 4, and can be compared to primary materials from the Gene Bank of the Crop Research Institute.

In comparing primary materials of winter barley from the Gene Bank, Crop Research Institute to finds at Dog Hill, the long diameter average of 14 *Hordeum*-type grains from the illustrated cultivation phase here is similar to the primary material, 38.8 μm, with a standard deviation of 0.9 μm, while annular diameter average in the same cultivation phase is 7.8 μm, with a standard deviation of 0.9 μm. This average is found in primary *Glyceria maxima* grains only in extreme cases, and the possibility that fourteen fossil grains belonging to this taxon are represented is minute, and can be disregarded. In addition, the largest *Hordeum*-type grains found at 3020 and 3050 mm are larger than any encountered in the primary materials. Similarly according to primary material, the ratio of **A**: **B** in Table 4 data is also considerably greater than 4:1 in all cases, excluding *Glyceria fluitans*. The annular rise of *Hordeum*-type grains from the same phase is 2.4 μm on average, very similar to Gene Bank accessions of primitive *Hordeum vulgare*, with a standard deviation of 0.4 μm. Of course, identification of scabbrae here is tautological (by virtue of definition of the *Hordeum*). Critically, annular diameters are very similar (~0.3 μm less than primary material, well within the standard deviation), with a similar incidence of a distinctively raised annulus. As noted above, small relative annular diameters (*vis a vis* long-diameter) are especially important for distinction of the *Hordeum*-type from large *Glyceria* grains. Small statistical differences noted reflect the fact that the identification of type is stricter in fossil pollen materials. Of course, smaller *Hordeum* grains noted in primary materials are more variable in size, including also relatively small (less than 38.0 μm long-diameter) grains, thus exhibiting also a greater standard deviation.

The duration of cultivation, based upon extreme 2-Sigma ranges of calibrated dates (Fig. 2; Table 5, 6), approximates 1 to 150 years at Dog Hill. This period is bracketed moreover by two major fires, with the initial fire being of local origin according to fall-out characteristics of the large microcharcoal (esp. that larger than 75 µm, see Blackford (2000)). This is followed by a modest increase in NAP and a decline of *Ulmus*, albeit temporary. The absence of heliotrophic weeds like *Plantago spp*. (which does not appear until the Elm Decline at Dog Hill), as well as an only sporadic representation of Chenopodiaceae and *Rumex acetosella* is notable. On the other hand, pinks are well represented, including *Cerastium*, as well as weeds like *Galium* that are more shade tolerant than plantains.

It would appear that the clearance involves small, semi-shaded areas, with the woodland canopy already partly broken by the drainage channel at Dog Hill, where importantly, standing water indicators (that would indicate a favourable situation for *Glyceria fluitans*) are absent. *Alnus*, as opposed to non-riparian verge arboreal species, suffers the major decline. Also important are the size-range characteristics of the Poaceae in the cultivation phase (and only in this phase), with a skewed representation by those grains in the range 34 to 36 microns (see Table 5), in the main diameter range of *Hordeum vulgare* and *Glyceria fluitans*, but larger than most grains of *Glyceria maxima*. This supports the identification of the *Hordeum*-type, as annulus characteristics of the latter also entirely exclude the possibility of *Glyceria fluitans* as a significant local element. Finally, there is a strong coincidence of coprophilous NPPs, including *Cercophora* (HdV-112), *Sporormiella* (HdV-113) and *Podospora* (HdV-368) with the cultivation phase (see Table 5), as would be promoted by animal browsing and grazing of open areas by either wild or domesticated species. Such browsing and grazing (note significantly large Poaceae levels) would also serve to fertilize local plots. In general, this is a convincing picture of early cultivation of barley by local inhabitants, taking place in small breaks in the woodland after a fire on a southern exposure more favourable to such cultivation at least two centuries prior to earliest recorded Neolithic settlement of the region. It is very similar to the ecology of a Late Mesolithic land-use phase at Black Heath (Ryan and Blackford 2009) and also

resembles a similarly situated and dated example of disturbance with cereal-type pollen at North Gill 1A on the North York Moors (Simmons and Innes 1996).

4. Discussion and conclusions

A comparison of pollen of a primitive variety of *Hordeum vulgare* obtained from the Gene Bank of the Crop Research Institute, Prague with UK native *Glyceria* species indicates a mostly non-problematic status of *G. maxima*, the most common species today, with respect to the distinction from *Hordeum vulgare*, if simple protocols are observed.

1. Only a marginal expression of *Glyceria maxima* grains above the cereal identification threshold (38.0 µm) might be expected in sample materials. However, *G. fluitans* is more problematic as to long-diameter, and up to one third of its grains will type-out as cereals.
2. An important caveat here is indicated by detailed comparative data, in that annular diameters of such problem grains are uniformly larger than those of *Hordeum vulgare*, with average annular diameters exceeding a ratio of 1: 4 vis a vis long grain diameter. Similar statistical trends are also evident, but less distinctive, in glycerol preparations (Joly et al. 2007), possibly due to the fact that annular diameter and long-diameter of grains respectively are differentially influenced by expansion in such preparations.
3. Thus in Mid-Holocene UK contexts, a reliable separation of *Hordeum vulgare* can be achieved with the latter type delimited by an outer annular diameter no greater than 8.5 µm and an average annular to long-diameter ratio of less than 1:4 under light-microscopic examination. Grains with very large annuli may in fact belong to *Glyceria fluitans*. A bi-modal expression of *Glyceria* is proposed with *G. maxima* exhibiting a better-defined outer annular (rise) and *Glyceria fluitans* a flattened outer annulus.

With respect to the general European *Glyceria* question, initial light-microscope investigations at Władysław Szafer Institute of Botany also indicate morphological

similarities of *G. aquatica* and *G. declinata* with a *G. fluitans*-type. Differences in scabbrae expression are also encountered in *Hordeum vulgare* and different *Glyceria* species, but not to an extent to be useful from the perspective of separating individual species. Further possibilities of clear differentiation of *Glyceria fluitans from Triticum* species are suggested by the strong (100% of cases) scabbrate expression in the former taxon. It is also pertinent to note that in Central Europe, there are multiple cases of Late Pleistocene and early Holocene sites containing what are clearly 'false' early cereals (Behre 2007). In Bohemia for example, an unpublished wetland site formed in czernozems areas at Hrabanovská černava near Lysa nad Labem in East Bohemia, analysed by Libor Petr, contains a rational sequence of Late Pleistocene to Early Holocene 'false cereals' (http://botany.natur.cuni.cz/palycz/), while unpublished late Pleistocene and Early Holocene sediments from Žatec in North Bohemia, a further czernozems region, also contain several score of apparently falsely identified early cereals (Petr Pokorný, pers. comm. 2012). Actually, many of these 'false' cereals type as *Avena* or *Triticum,* and thus are not to be confused with *Hordeum* (http://botany.natur.cuni.cz/palycz/). In cases of such non-*Hordeum* types, further systematic comparisons of wild grass types, and particularly diploidic steppe grasses (Petr Pokorný, pers. com. 2014) may be rewarding, given the wide edaphic aspect indicated by the most frequent 'false' early cereal finds in lowland czernozems areas and in sediments dating to Late Pleistocene and Early Holocene times. A further notable example is Lake Schwarzenberg in South Bohemia (Pokorný et al. 2009), where possible early cereals are coeval with the early farming horizon in Central and Eastern Europe. Here, more plausibly dated (circa 7000 cal. yr BP) cereal pollen occurs with high charcoal levels in lake sediments coeval with the Early Neolithic Linienbandkeramik in South Bohemia (such sites are ~75 km from Schwarzenburg Lake) in one profile (Trench 3), while much earlier pseudo-cereal (cf. *Avena*) types are also found in a supplemental core (01/9), complicating interpretation of finds from Trench 3. Such Central European settings are more ecologically diverse than the UK, and may produce a variety of problematic Poaceae, including steppic species that tolerate extreme weather variations with a view to the transgressive pattern of 'false' cereal representation over the Holocene boundary at some sites, and relate to species

outside the genus *Glyceria*. The strict protocols presented here and applied to Dog Hill, however, point to a utility of palynology in the definition of early farming horizons in Europe, once analytic efforts also seriously address the 'false' cereal problem.

Results of this work indicate a research potential for palynology in identifying the farming transition in UK peat uplands and potentially, inland basins in Late Mesolithic and Early Neolithic contexts, and particularly barley cultivation. A *Hordeum*-focus of early horticulture is for example indicated by initial data from Terminal Mesolithic rod site contexts at Esklets in the upper Esk River valley on the North York Moors (Albert and Innes 2015). This preference may be related in part to a wider edaphic tolerance of *Hordeum* (*vis a vis* early *Triticum* varieties), cf. Lister et al. (2009) in marginal agro-climates of the northern UK in the 6th Millennium BP, and it is possible that among early agriculturalists, barley may be a preferred cultigen rather than other cereal crops. It is not inconceivable that such barley production reflects its use in alcoholic drink as well as food on the part of humans.

At Dog Hill, non-pollen palynomorphs and microcharcoal data also support a case for cultivation, with an ecology that might be described as containing mixed Mesolithic and Neolithic characteristics: there is a substantial *Melampyrum* curve during the disturbance phase, typical of Mesolithic-age fire disturbances, but also low values of ruderal herbs that are more typical of Neolithic pastoralism, including *Artemisia* and Chenopodiaceae (Simmons and Innes 1996; Innes et al. 2013). The association of these weeds with *Hordeum* pollen is a common feature of early Neolithic pollen diagrams in Britain (cf. Farrell 2015). This disturbance ecology at Dog Hill, particularly regarding elevated *Cercophora* and no *Plantago lanceolata*, is almost isomorphic to that at nearby Black Heath, which is also situated in the environs of a cluster of Mesolithic sites, and so land use of that period is inferred (Ryan and Blackford, 2010). Other Mesolithic age disturbances in the southern Pennines, of which there are several, are also similar in scale, age and character (Radley et al. 1974; Williams 1985; Tallis and Switsur 1990). The Dog Hill case is moreover distinct from coastal sites examined by Tweddle et al. (2005) and Joly et al. (2007) in that early cereals

identified at Dog Hill are stratigraphically constrained to a single pollen zone (note that only the 15% of pollen spectra that cover the relevant part of the Dog Hill diagram are presented here) that is also coeval with major, Terminal Mesolithic occupation evidence: five rod microlith sites situated within a 0.5 km radius, including a shallow basin which may have formed a focus for human activity. At Dog Hill potential early cereals are not found outside major disturbance levels. Low impact cultivation oriented upon southern exposures and breaks in canopy cover in the region, alongside more traditional hunter-gatherer subsistence practises, is suggested. Such barley cultivation, approximately two centuries prior to the main Early Neolithic horizon in the British Isles, is suggestive of a hunter-gatherer role in the spread of agriculture, at least in the upland UK, and incidentally, might be related to the early Neolithic colonization of Ireland when floral and faunal aspects of the Neolithic package from sites in both Ballynagilly (Pilcher and Smith 1979) and Ferriters Cove (Woodman 2000) respectively are considered, with such immigrant populations (Garrow and Sturt 2011) comprising a potential source of cultigens.

Acknowledgements

The research at Dog Hill was funded by the Leverhulme Trust under project F/00128/BD. Radiocarbon dating was carried out at SUERC Radiocarbon Dating Laboratory, Glasgow, UK. We acknowledge the kind assistance of Vojtech Holubec of the Gene Bank, Crop Research Institute, Prague and John Durkin of the Botanical Society of the British Isles in the collection of materials.

Author biographies

BRUCE ALBERT is a PDRA at the Department of Archaeology, University of Durham, engaged in the Nebelivka Megasite Project in Ukraine. Prior appointments include the Czech Life Sciences University, Department of Ecology and The University of Texas at Austin Geo-archaeology Laboratory, with a special focus on early farming in

Eastern Europe as well as alluvial palynology in the Old and New World including work in Texas and North Mexico.

JAMES INNES is retired Experimental Officer and Lecturer in Physical Geography in the Geography Department, Durham University, UK., where he obtained his Ph.D. in 1989 on the fine-resolution palynology of mid-Holocene blanket peats on the North York Moors in north-east England. He has held research and lecturing posts at the University of Liverpool and at Queen Mary College, University of London. He has worked on vegetation history in North America and China, and the main focus of his research is on human-environmental relations in the British Mesolithic and the transition to the Neolithic.

References

Albert BM, Innes JB. 2015. Multi-profile fine-resolution palynological and micro-charcoal analyses at Esklets, North York Moors, UK, with special reference to the Mesolithic-Neolithic transition. Vegetation History and Archaeobotany, 24:357-375.

Andersen T. 1979. Identification of wild grass and cereal pollen. Dan Geol Unders Árb, p. 69–92.

Armit I, Murphy E, Nelis E, Simpson D. 2003. Neolithic settlement in Ireland and western Britain. Oxford, Oxbow Books.

Bakels C.C. 1992. The botanical shadow of two early Neolithic settlements in Belgium: carbonised seeds and disturbances in a pollen record. Review of Palaeobotany and Palynology 73:1-19.

Bartley DD. 1975. Pollen analytical evidence for prehistoric forest clearance in the upland area west of Rishworth, W. Yorkshire. New Phytologist 74:375-381.

Behre KE. 2007. Evidence for Mesolithic agriculture in and around central Europe? Vegetation History and Archaeobotany 16:203-219.

Behre KE, Kučan D. 1986. Die Reflektion archäologisch bekannter Siedlungen in Pollendiagrammen verschiedener Entfernung-Beispiele aus der Siedlungskammer Flögeln, Nordwestdeutschland. In: Behre KE, editor, Anthropogenic Indicators in Pollen Diagrams. Rotterdam, Balkema.

Beug H-J. 2004. Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete. München, Pfeil.

Blackford JJ. 2000. Charcoal fragments in surface samples following a fire and the implications for interpretation of subfossil charcoal data. Palaeogeography, Palaeoclimatology, Palaeoecology, 164:33-42.

Blackford JJ, Innes JB, Hatton JJ, Caseldine CJ. 2006. Mid-Holocene environmental change at Black Ridge Brook, Dartmoor, SW England: a new appraisal based on fungal spore analysis. Review of Palaeobotany and Palynology 141:189-201.

Cugny C, Mazier F, Gallop D. 2010. Modern and fossil non-pollen palynomorphs from the Basque mountains (western Pyrenees, France): the use of coprophilous fungi to reconstruct pastoral activity. Vegetation History and Archaeobotany 19:391-408.

Darvill T. 2003. Billown and the Neolithic of the Isle of Man. In: Armit I, Murphy E, Nelis E, Simpson D, editors. Neolithic settlement in Ireland and western Britain. Oxford: Oxbow Books; p. 112-119.

Dickson C. 1988. Distinguishing cereal from wild type grass pollen: some limitations. Circaea 5:67–71.

Edwards KJ. 1989. The cereal pollen record and early agriculture. In: Milles A, Williams D, Gardner N, editors. The Beginnings of Agriculture. International Series 496, British Archaeological Reports: Oxford; p. 113–135.

Edwards KJ, Hirons KR, 1984. Cereal pollen grains in pre-elm decline deposits: implications for the earliest agriculture in Britain. Journal of Archaeological Science 11:71–80.

Eubanks M.1997. Reevaluation of the Identification of Ancient Maize Pollen from Alabama. American Antiquity 62:139-45.

Faegri K, Kalland PE, Krzywinski K. 1989. Textbook of Pollen Analysis. Wiley, Chichester.

Farrell M. 2015. Later prehistoric vegetation dynamics and Bronze Age Agriculture at Hobbister, Orkney, Scotland. Vegetation History and Archaeobotany 24:467-486.

Garrow D, Sturt F. 2011. Grey waters bright with Neolithic Argonauts? Maritime connections and the Mesolithic-Neolithic transition within the ‘western seaways’ of Britain, c. 5000 – 3500 BC. Antiquity 85:59-72.

Garton D. 1991. Neolithic settlement in the Peak District: perspective and prospects. In: Hodges R, Smith K, editors. Recent developments in the Archaeology of the Peak District (Sheffield Archaeological Monographs 2). University of Sheffield: Sheffield; p. 3-21.

Green M, Allen MJ, 1997. An early prehistoric shaft on Cranborne Chase. Oxford Journal of Archaeology 16:121-132.

Griffiths S. 2014. Points in time: the Mesolithic–Neolithic Transition and the chronology of late rod microliths in Britain. Oxford Journal of Archaeology 33:221-243.

Hall AR, Huntley JP. 2007. A review of the evidence for macrofossil plant remains from archaeological deposits in Northern England. English Heritage Research Department Report Series 87. 451p.

Hall VA, Pilcher JR, Bowler M. 1993. Pre-Elm Decline cereal size pollen: evaluating its recruitment to fossil deposits using modern pollen rain studies. Biology and Environment (Proceedings of the Royal Irish Academy) 93B:1–4.

Innes JB, Blackford JJ, Chambers FM. 2006. *Kretzschmaria deusta* and the northwest European mid‐Holocene *Ulmus* decline at Moel y Gerddi, north Wales, United Kingdom. Palynology 30:121-132.

Innes JB, Blackford JJ, Davey PJ. 2003a. Dating the introduction of cereal cultivation to the British Isles: early palaeoecological evidence from the Isle of Man. Journal of Quaternary Science 18;603-613.

Innes JB, Blackford JJ, Rowley-Conwy PA. 2003b. The start of the Mesolithic-Neolithic transition in north-west Europe - the palynological contribution. Antiquity.ac.uk/ProjGall/v.77, no.297.

Innes JB, Blackford JJ, Rowley-Conwy PA. 2013. Late Mesolithic and early Neolithic forest disturbance: a high resolution palaeoecological test of human impact hypotheses. Quaternary Science Reviews 77:80-100.

Innes JB, Simmons IG. 2000. Mid-Holocene charcoal stratigraphy, fire history and palaeoecology at North Gill, North York Moors, UK. Palaeogeography, Palaeoclimatology, Palaeoecology 164:151-165.

Jacobi RM, Tallis JH, Mellars PA. 1976. The southern Pennine Mesolithic and the ecological record. Journal of Archaeological Science 3:307-320.

Joly C, Barille L, Barreau M, Mancheron A, Visset L. 2007. Grain and annulus diameter as criteria for distinguishing pollen grains of cereals from wild grasses. Review of Palaeobotany and Palynology 146:221-233.

Joly C, Visset L. 2009. Evolution of vegetation landscapes since the Late Mesolithic on the French West Atlantic coast. Review of Palaeobotany and Palynology 154:124-179.

Jones G. 2000. Evaluating the importance of cultivation and collecting in Neolithic Britain. In: Fairbairn AS, editor. Plants in Neolithic Britain and beyond. Oxbow Books: Oxford; p. 79-84.

Köhler E, Lange E. 1979. A contribution to distinguishing cereal from wild grass pollen grains by LM and SEM. Grana 18:133–140.

Lambert JM. 1947. Biological flora of the British Isles: *Glyceria maxima* (Hartm.) Holmb. Journal of Ecology 34:310-344.

Lister DL, Thaw S, Bower MA, Jones H, Charles MP, Jones G, Jones MK. 2009. Latitudinal variation in a photoperiod response gene in European barley: insight into the dynamics of agricultural spread from 'historic' specimens. Journal of Archaeological Science 36:1092-1098.

López-Sáez JA, López-Merino L. 2007. Coprophilous fungi as a source of information of anthropic activities during the prehistory in the Amblés valley (Ávila, Spain): the archaeopalynological record. Revista Española de Micropaleontologia 39:103-116.

McClatchie M, Bogaard A, Colledge S, Whitehouse NJ, Schulting RJ, Barratt P, McLaughlin TR. 2014. Neolithic farming in north-western Europe:

archaeobotanical evidence from Ireland. Journal of Archaeological Science 51:206-215.

Mellars PA. 1976. Settlement patterns and industrial variability in the British Mesolithic. In: Sieveking GdeG, Longworth IH, Wilson KE, editors. Problems in economic and social archaeology. London: Duckworth; p. 375-399.

Out WA. 2008. Neolithisation at the site of Brandwijk-Kerkhof, the Netherlands: natural vegetation, human impact and plant food subsistence. Vegetation History and Archaeobotany 17:25-39.

Parker AG, Goudie AS, Anderson DE, Robinson MA, Bonsall C. 2002. A review of the mid-Holocene Elm Decline in the British Isles. Progress in Physical Geography 26:1–45.

Pilcher JR, Smith AG. 1979. Palaeoecological investigations at Ballynagilly, a Neolithic and Bronze Age settlement in County Tyrone, Northern Ireland. Philosophical Transactions of the Royal Society B: Biological Sciences 286: 345-369.

Pokorný P, Šída P, Chvojka O, Žáčková P, Kuneš P, Světlík I, Vesel J. 2009. Paleoenvironmentální výzkum zaniklého jezera Schwarzenberg v jižních Čechách anavazující průzkum mezolitického archeologického prostoru. Památky Archeologické 101:5-38.

Radley J, Tallis JH, Switsur VR. 1974. Excavation of three “narrow blade” Mesolithic sites in the southern Pennines. Proceedings of the Prehistoric Society 40:1-19.

Regnell M. 2012. Plant subsistence and environment at the Mesolithic site Tågerup, southern Sweden: new insights on the “Nut Age”, Vegetation History and Archaeobotany 21:1-16.

Rodwell JS. 1991. British plant communities. Vol.2, Mires and heaths. Cambridge: Cambridge University Press.

Rodwell JS. 1995. British plant communities. Vol.4, Aquatic communities, swamps and tall-herb fens. Cambridge: Cambridge University Press.

Ryan P, Blackford JJ. 2009. Late Mesolithic environmental change in the upland zone of Britain: high resolution records of woodland disturbance and fire. In: Crombé P, van Strydonck M, Sergant J, Boudin M, Bats M, editors. Chronology and evolution within the Mesolithic of north-west Europe. Cambridge Scholars Publishing: Cambridge; p. 591-613.

Ryan PA, Blackford JJ. 2010. Late Mesolithic environmental change at Black Heath, south Pennines, UK: a test of Mesolithic woodland management models using pollen, charcoal and non-pollen palynomorph data. Vegetation History and Archaeobotany 19:545-558.

Simmons IG. 1996. The environmental impact of later Mesolithic cultures. Edinburgh University Press, Edinburgh.

Simmons IG, Innes JB. 1987. Mid-Holocene adaptations and later Mesolithic forest disturbance in Northern England. Journal of Archaeological Science 14: 385-403.

Simmons IG, Innes JB. 1996. The ecology of an episode of prehistoric cereal cultivation on the North York Moors, England. Journal of Archaeological Science 23:613-618.

Smith AG, Pilcher JR. 1973. Radiocarbon dates and vegetational history of the British Isles. New Phytologist 72:903-914.

Smith C. 1992. Late Stone Age hunters of the British Isles. London: Routledge.

Spikins PA. 2002. Prehistoric People of the Pennines. Leeds: West Yorkshire Archaeology Service.

Switsur VR, Jacobi RM. 1975. Radiocarbon dates for the Pennine Mesolithic. Nature 256:32-34.

Tallis JH, Switsur VR. 1990 Forest and moorland in the south Pennine uplands in the mid-Flandrian period: II. The hillslope forests. Journal of Ecology 78: 857-883

Thomas J. 2007. Mesolithic-Neolithic transitions in Britain: from essence to inhabitation. Proceedings of the British Academy 144:423-440.

Tinner W, Nielsen EH, Lotter AF. 2007. Mesolithic agriculture in Switzerland? A critical review of the evidence. Quaternary Science Reviews 26:1416-1431.

Tipping R, Bunting MJ, Davies AL, Murray H, Fraser S, McCulloch RD. 2009. Modelling land use around an early Neolithic timber ‘hall’ in north east Scotland from high spatial resolution pollen analyses. Journal of Archaeological Science 36:140-149.

Tweddle JC, Edwards KJ, Fieller NRJ. 2005. Multivariate statistical and other approaches for the separation of cereal from wild Poaceae pollen using a large Holocene dataset. Vegetation History and Archaeobotany 14:15–30.

Whittle A. 2007. The temporality of transformation: dating the early development of the southern British Neolithic. Proceedings of the British Academy 144:377-398.

Williams CT. 1985. Mesolithic Exploitation Patterns in the Central Pennines. A Palynological study of Soyland Moor. British Archaeological Reports, British Series 139, Oxford.

Williams E. 1989. Dating the introduction of food production into Britain and Ireland. Antiquity 63:518-521.

Wiltshire P, Edwards KJ. 1993. Mesolithic, early Neolithic, and later prehistoric impacts on vegetation at a riverine site in Derbyshire, England. In: Chambers FM, editor. Climate Change and Human Impact on the Landscape. London: Chapman & Hall; p.157-168.

Woodbridge J., Fyfe R.M., Roberts N., Downey S., Edinborough K., Shennan S. 2014. The impact of the Neolithic agricultural transition in Britain: a comparison of pollen-based land-cover and archaeological ^{14}C date-inferred population change. Journal of Archaeological Science 51:216-224.

Woodman PC. 2000. Getting back to basics: transitions to farming in Ireland and Britain. In: Price TD, editor. Europe's First Farmers. Cambridge University Press: Cambridge; p. 219-259.

Young R. 1990. Mixed lithic scatters and the Mesolithic-Neolithic transition in north-east England: a speculation. In: Brooks I, Philips P, editors. Breaking the Stony Silence. British Archaeological Reports, British Series 213, Oxford; p. 161-185.

Captions to figures

Fig.1

Location of the Dog Hill pollen site (DH), on Rishworth Moor in the southern Pennines, United Kingdom, at National Grid Reference SE001171. Black squares represent

‘rod’ microlith flint sites, believed to be of Terminal Mesolithic age. The open square represents a Neolithic stone axe find. Contours are in metres above sea level.

Fig. 2

Selected taxa pollen, microcharcoal and non-pollen palynomorph (NPP) diagram for part of the pre-Elm Decline levels at Dog Hill. Frequencies are calculated as percentages of the total land pollen sum.

Fig. 3

Photomicrographs of measured pollen grains of (a) *Hordeum*, (b) *Glyceria maxima* and (c) *Glyceria fluitans*. Measurements are: long diameter of grain 39 ìm, annulus diameter 8 ìm (*Hordeum*); long diameter of grain 31 ìm, annulus diameter 6 ìm (*G. maxima*) and long diameter of grain
38 ìm, annulus diameter 9.9 ìm (*G. fluitans*)

Tables

Table 1. *Hordeum vulgare* (winter), Crop Research Institute (Prague, CZ) Gene Bank accession number 01 CO 502100 (1-25) and 01 CO 502101 (26-50): measurements of individual pollen grain diameter, annulus diameter and annulus rise as well as characterizations of annulus rise and scabbrae definition under silicone oil preparation.

Grain #	Diameter 1 (long) µm	Diameter 2 (short) µm	Diameter average µm	Annulus Diameter 1 µm	Annulus Diameter 2 µm	Ann, diameter average µm	Annulus rise (w/intine) measured	Relative annulus rise	? Scabbrae well-defined
1	43.0	36.0	39.5	8.5	7.5	8.0	Obscured	Raised	Yes
2	44.5	43.0	43.75	Obs.	Obs.	N/a	Obscured	Raised	Yes
3	45.0	33.0	39.0	Obs.	Obs.	N/a	2.0	Raised	Yes
4	44.5	36.0	40.25	7.5	7.5	7.5	2.5	Raised	Yes
5	37.0	26.0	31.5	8.5	8.5	8.5	2.0	Raised	Yes

6	34.0	38.0	36.0	8.0	8.0	8.0	3.0	Raised	Yes
7	34.0	33.5	33.75	8.0	8.0	8.0	Obscured	Raised	Yes
8	39.0	34.0	36.5	8.0	8.0	8.0	3.0	Raised	Yes
9	35.5	35.0	35.25	8.0	8.0	8.0	3.0	Raised	Yes
10	32.0	32.0	32.0	7.5	7.5	7.5	3.0	Raised	Yes
11	37.0	30.0	33.5	7.5	7.5	7.5	3.0	Raised	Yes
12	39.5	37.0	38.25	8.0	8.0	8.0	2.0	Raised	Yes
13	40.0	38.5	39.25	9.0	8.5	8.75	Obscured	Raised	No
14	41.0	40.0	40.5	8.0	7.0	7.5	Obscured	Raised	Yes
15	36.0	30.0	33.0	Obs.	Obs.	N/a	Obscured	Raised	Yes
16	38.0	35.0	36.5	7.5	7.5	7.5	2.0	Raised	Yes
17	41.0	35.0	38.0	9.0	8.5	8.75	2.5	Raised	Yes
18	44.0	40.0	42.0	10.0	7.5	8.75	Obscured	Raised	Yes
19	45.5	40.0	42.25	9.0	8.5	8.75	Obscured	Raised	Yes
20	40.0	33.5	36.75	8.0	8.0	8.0	Obscured	Raised	Yes
21	40.0	37.0	38.5	Obs.	Obs.	N/a	Obscured	Obs.	No
22	40.0	34.5	37.25	Obs.	Obs.	N/a	Obscured	Raised	Yes
23	41.0	34.0	37.5	8.0	7.5	7.75	Obscured	Raised	Yes
24	39.5	38.0	38.75	9.0	9.0	9.0	2.0	Raised	Yes
25	33.0	30.0	31.5	8.0	8.5	8.25	Obscured	Raised	Yes
26	31.0	31.0	31.0	7.0	7.0	7.0	2.0	Raised	No
27	40.5	33.0	36.75	9.0	8.5	8.75	2.5	Raised	Yes
28	42.5	39.0	40.75	9.0	7.0	8.0	Obscured	Raised	Yes
29	35.0	34.5	34.75	8.0	8.0	8.0	Obscured	Raised	Yes
30	39.5	36.0	37.75	7.0	7.0	7.0	Obscured	Raised	Yes
31	43.0	37.0	40.0	8.0	7.5	7.75	Obscured	Raised	No
32	40.0	37.5	38.75	Obs.	Obs.	Obs.	Obscured	Raised	No
33	42.0	39.0	40.5	8.0	8.0	8.0	2.5	Raised	Yes
34	39.0	36.0	37.5	7.0	7.0	7.0	2.0	Raised	Yes
35	41.0	33.5	37.25	8.5	8.5	8.5	Obscured	Raised	Yes
36	42.0	36.0	39.0	8.0	9.0	8.5	Obscured	Raised	Yes
37	36.0	32.5	34.25	8.0	8.0	8.0	2.5	Raised	Yes
38	40.0	36.0	38.0	10.0	7.0	8.5	Obscured	Raised	Yes
39	39.0	30.0	34.5	Obs.	Obs.	Obs.	Obscured	Obs.	No
40	49.0	39.0	44.0	9.0	9.0	9.0	Obscured	Obs.	No
41	36.0	33.5	34.75	7.5	7.0	7.25	Obscured	Raised	Yes

42	40.5	36.0	38.25	8.0	8.0	8.0	2.0	Raised	Yes
43	40.0 m	39.5	39.75	8.5	7.0	7.75	Obscured	Raised	Yes
44	40.0	35.0	37.5	8.0	8.5	8.25	Obscured	Raised	Yes
45	47.0	45.5	46.25	10.0	9.5	9.75	Obscured	Raised	Yes
46	33.0	32.5	32.75	8.0	7.5	7.75	Obscured	Raised	Yes
47	40.0	36.0	38.0	9.0	8.5	8.75	3.0	Raised	Yes
48	42.0	37.0	39.5	Obs.	Obs.	Obs.	Obscured	Obs.	Yes
49	39.0	32.0	35.5	Obs.	Obs.	Obs.	2.0	Raised	Yes
50	40.0	36.0	37.5	Obs.	Obs.	Obs.	Obscured	Obs.	Yes

Table 2. *Glyceria maxima*, Tyne Valley (UK): measurements of individual pollen grain diameter, annulus diameter and annulus rise as well as characterizations of annulus rise and scabbrae definition under silicone oil preparation.

Grain #	Diameter 1 (long) µm	Diameter 2 (short) µm	Diameter average µm	Annulus Diameter 1 µm	Annulus Diameter 2 µm	Ann, diameter average µm	Annulus rise (w/intine) measured	Relative annulus rise	? Scabbrae well-defined
1	37.0	34.0	35.5	6.0	6.0	6.0	1.5	Low	Yes
2	36.5	31.5	34.0	6.0	6.0	6.0	Obscured	Low	Yes
3	37	32.5	34.75	6.0	6.0	6.0	1.0	Low	Yes
4	30	24.5	27.75	Obs.	Obs.	Obs.	1.0	Low	No
5	35	32.5	32.25	5.0	5.5	5.25	1.0	Low	No
6	35	34.5	34.75	5.5	6.0	5.75	Obscured	Low	Yes
7	32.5	26.0	29.25	Obs.	Obs.	Obs.	Obscured	Low	Yes
8	35.0	35.0	35.0	5.0	5.5	5.25	2.0	Obs.	Yes
9	35.0	34.5	34.75	7.0	7.0	7.0	2.0	Obs.	No
10	35.0	32.5	33.75	7.0	7.5	7.25	1.5	Low	No

11	32.5	30.0	31.25	6.0	6.5	6.25	1.0	Low	No
12	32.5	26.5	29.5	7.0	7.0	7.0	1.0	Low	No
13	30.0	25.0	27.5	6.5	6.0	6.25	2.0	Obs.	No
14	32.5	28.0	30.25	6.0	6.0	6.0	1.5	Obs.	No
15	35.0	35.0	35.0	7.5	7.0	7.25	1.0	Obs.	No
16	32.5	30.0	31.25	7.0	7.0	7.0	1.5	Raised	Yes
17	32.5	32.5	32.5	6.5	6.0	6.25	2.5	Raised	No
18	38.5	33.0	35.75	7.0	7.0	7.0	2.0	Raised	Yes
19	37.0	34.0	35.5	7.0	7.5	7.25	2.5	Raised	Yes
20	32.5	32.0	32.25	6.0	6.5	6.25	Observed	Raised	Yes
21	35.0	35.5	35.25	7.0	7.5	7.25	Obscured	Raised	Yes
22	31.0	24.5	27.25	6.5	6.0	6.25	Obscured	Low	Yes
23	34.5	29.0	31.75	7.0	7.0	7.0	Obscured	Low	No
24	30.5	24.5	27.5	5.0	5.5	5.25	Obscured	Low	Yes
25	32.5	28.0	30.25	7.0	7.5	7.25	2.0	Raised	Yes
26	30.0	26.0	28.0	6.0	6.0	6.0	1.0	Low	Yes
27	35.0	34.5	34.75	6.5	6.0	6.25	1.0	Low	Yes
28	32.5	30.0	31.25	6.0	6.0	6.0	1.0	Low	Yes
29	32.5	29.5	31.0	6.0	6.5	6.25	1.5	Raised	Yes
30	30.0	25.0	27.5	6.0	6.0	6.0	Obscured	Obs.	Yes
31	25.0	21.5	23.25	5.0	5.5	5.25	1.0	Low	Yes
32	27.5	25.0	26.25	7.0	6.5	6.75	1.0	Low	Yes
33	32.5	26.0	29.25	6.5	6.5	6.5	1.5	Raised	Yes
34	31.5	27.0	29.25	Obs.	Obs.	Obs.	1.0	Low	Yes
35	31.5	27.0	29.25	Obs.	Obs.	Obs.	1.0	Low	Yes
36	32.5	32.5	32.5	7.5	7.5	7.5	1.5	Obs.	Yes
37	35.0	29.0	32.0	7.5	7.5	7.5	1.5	Obs.	No
38	33.5	33.0	33.25	8.0	7.5	7.75	1.0	Low	No
39	32.5	30.0	31.25	7.0	7.0	7.0	1.0	Low	Yes
40	25.0	24.0	24.5	4.5	5.0	4.75	1.0	Low	Yes
41	31.5	27.0	29.25	7.0	7.0	7.0	1.0	Raised	Yes
42	30.0	30.0	30.0	6.5	7.0	6.75	1.0	Obs.	Yes
43	35.0	35.0	35.0	7.0	7.0	7.0	1.0	Low	Yes
44	31.5	30.5	31.0	7.0	7.0	7.0	Obscured	Raised	Yes
45	30.0	30.0	30.0	7.5	7.0	7.25	Obscured	Raised	Yes
46	32.5	32.0	32.25	7.5	7.5	7.5	1.5	Raised	Yes

47	25.0	23.0	24.0	5.0	5.5	5.25	1.5	Raised	Yes
48	35.0	35.0	35.0	7.5	7.0	7.25	1.0	Raised	Yes
49	30.0	30.0	30.0	7.0	7.0	7.0	Obscured	Obs.	Yes
50	32.5	30.0	31.25	8.5	8.0	8.25	Obscured	Obs.	Yes

Table 3. *Glyceria fluitans*, Tyne Valley (UK): measurements of individual pollen grain diameter, annulus diameter and annulus rise as well as characterizations of annulus rise and scabbrae definition under silicone oil preparation.

Grain #	Diameter 1 (long) µm	Diameter 2 (short) µm	Diameter average µm	Annulus Diameter 1	Annulus Diameter 2	Ann, diameter average µm	Annulus rise (w/intine) measured	Relative annulus rise	? Scabbrae well-defined
1	38.5	38.0	38.25	10.0	10.0	10.0	1.5	Raised	Yes
2	39.0	39.0	39.0	10.0	10.0	10.0	Obscured	Obs.	Yes
3	38.5	33.5	36.0	9.0	10.0	9.5	2.5	Low	Yes
4	38.0	37.5	37.75	10.0	10.0	10.0	1.0	Low	Yes
5	35.5	35.0	35.25	9.0	9.0	9.0	2.0	Low	Yes
6	39.5	38.0	38.75	9.5	9.0	9.25	Obscured	Obs.	Yes
8	38.5	35.5	37.0	9.0	9.0	9.0	2.0	Raised	Yes
9	35.0	32.5	33.75	10.0	10.0	10.0	1.0	Raised	Yes
10	35.0	34.5	34.25	9.0	9.0	9.0	1.5	Raised	Yes
11	32.5	32.5	32.5	10.0	10.0	10.0	1.0	Low	Yes
12	33.0	31.0	32.0	10.0	10.0	10.0	1.0	Low	Yes
13	37.0	35.0	36.0	10.0	10.0	10.0	1.0	Low	Yes

14	38.5	38.0	38.25	10.0	11.0	10.5	1.5	Low	Yes
15	34.5	34.0	34.25	9.0	9.0	9.0	2.0	Low	Yes
16	39.0	38.5	38.75	10.0	10.0	10.0	1.0	Low	Yes
17	35.0	35.0	35.0	10.0	9.5	9.75	1.0	Raised	Yes
18	32.0	30.0	31.0	9.0	9.0	9.0	2.0	Raised	Yes
19	30.0	30.0	30.0	10.0	9.0	9.5	2.5	Raised	Yes
20	32.5	28.5	30.5	9.5	9.0	9.25	Observed	Obs.	Yes
21	34.5	34.0	34.25	8.5	9.5	9.0	Obscured	Obs.	Yes
22	30.0	22.5	26.75	9.0	10.0	9.5	Obscured	Low	Yes
23	35.0	34.5	34.75	9.5	10.0	9.75	Obscured	Obs.	Yes
24	35.0	35.0	35.0	9.0	10.0	9.5	Obscured	Obs.	Yes
25	38.0	37.0	37.5	10.0	9.0	9.5	1.0	Raised	Yes
26	35.0	30.5	32.75	10.0	10.0	10.0	1.0	Low	Yes
27	38.5	38.0	38.25	10.0	10.0	10.0	1.0	Low	Yes
28	38.0	38.0	38.0	10.0	10.0	10.0	1.0	Low	Yes
29	38.0	37.0	37.5	10.0	10.0	10.0	1.0	Low	Yes
30	34.0	32.0	33.0	9.0	10.0	9.5	Observed	Raised	Yes
31	35.0	35.0	35.0	9.0	10.0	9.5	1.5	Obs.	Yes
32	35.5	35.0	35.25	9.0	9.5	9.25	1.5	Low	Yes
33	37.5	37.0	37.25	10.0	10.0	10.0	1.5	Low	Yes
34	40.0	39.5	39.75	10.0	10.5	10.25	1.5	Low	Yes
35	34.0	34.0	34.0	Obs.	Obs.	Obs.	2.0	Low	Yes
36	35.0	30.0	32.5	10.0	10.0	10.0	1.0	Low	Yes
37	30.0	25.0	27.5	9.0	9.5	9.25	1.0	Low	Yes
38	34.5	34.5	34.5	9.0	10.0	9.5	1.5	Low	Yes
39	35.0	35.0	35.0	9.0	9.0	9.0	1.0	Low	Yes
40	32.5	30.5	31.5	10.0	10.0	10.0	1.5	Low	Yes
41	35.0	35.0	35.0	10.0	9.0	9.5	1.0	Low	Yes
42	38.5	38.0	38.25	10.0	10.0	10.0	1.0	Low	Yes
43	34.5	30.0	32.25	10.0	9.5	9.75	1.0	Low	Yes
44	36.5	36.5	36.5	9.0	10.0	9.5	Obscured	Low	Yes
45	39.5	39.0	39.25	10.5	10.5	10.5	Obscured	Low	Yes
46	35.0	29.0	32.0	8.5	9.0	8.75	1.5	Obs.	Yes
47	38.5	36.5	37.5	9.0	9.0	9.0	1.0	Low	Yes
48	40.0	34.5	36.75	10.5	10.0	10.25	1.0	Low	Yes
49	37.5	35.0	36.25	10.0	10.0	10.0	Obscured	Low	Yes

50	32.0	32.0	32.0	8.5	9.0	8.75	Obscured	Low	Yes

Table 4. Dog Hill cultivation phase: measurements of individual pollen grain diameter, annulus diameter and annulus rise as well as characterizations of annulus rise and scabbrae definition under silicone oil preparation.

Level (mm)	Diameter 1 (long, **A**) µm	Diameter 2 µm	Diameter average µm	Annulus diameter 1 µm	Annulus diameter 2 µm	Annulus diameter average (**B**) µm	Annulus Rise µm	Relative annulus Rise (w/ intine) µm	Scabbrae well-defined?
3020	41.0	37.0	39.0	8.0	8.0	8.0	3.0	Raised	Yes
3030	38.5	36.0	37.25	7.5	7.5	7.5	2.5	Raised	Yes
3030	39.0	36.5	37.75	8.5	7.5	8.0	3.0	Raised	Yes
3030	38.0	35.5	36.75	7.5	7.5	7.5	2.0	Raised	Yes
3030	39.0	36.0	37.5	7.5	7.5	7.5	2.5	Raised	Yes
3035	38.5	36.0	37.25	7.5	7.5	7.5	3.0	Raised	Yes
3035	38.5	34.5	36.5	7.5	7.5	7.5	2.0	Obs.	Yes
3040	39.0	37.0	38.0	8.0	8.0	8.0	3.0	Raised	Yes

3050	41.0	38.0	39.5	8.5	8.5	8.25	3.0	Raised	Yes
3050	38.5	36.5	37.5	8.0	7.5	7.75	2.5	Raised	Yes
3050	38.0	35.5	36.75	7.5	7.5	7.5	2.0	Obs.	Yes
3050	38.5	36.0	37.25	8.0	8.0	8.0	3.0	Raised	Yes
3050	39.0	37.0	38.0	8.5	8.0	8.25	3.0	Raised	Yes
3055	38.5	36.5	37.5	8.0	8.0	8.0	3.0	Raised	Yes

Table 5. Dog Hill cultivation phase, selected counts

Depth (mm)	3055	3050	3045	3040	3035	3330	3325	3220
Ulmus	23	10	18	16	11	4	11	33
Calluna	39	12	23	18	18	14	6	106
Hordeum 40-41 µm		1						1
Hordeum 38-39 µm	1	4		1	2	4		
Poaceae 34-37 µm	17	16		5	11	16	15	2
Poaceae 31-33 µm		5		7	3	6	7	2
Poaceae 28-30 µm	8	18	3	10	8	6	22	9
Poaceae 27- µm	141	299	102	148	212	269	246	56
Chenopodiaceae	3					2		
Melampyrum	8	13	8	7	27	42	26	
Galium						1		
Artemisia			2					
Cerastium					1	2		
Scleranthus							1	
Rumex acetosella							2	
Gelasinospora		3		6	2			
Gelasniospora		1						
Cercophora		62		32	51	95	131	3

Sporomiella						3	5	
Podospora		3		3		1		
Charcoal 1-25 µm	30	1428	23	35	23	10	13	777
Charcoal 26-50 µm	5	378	12	25	15	5	17	140
Charcoal 51-75 µm	2	94	3	12	9	6	4	70
Charcoal 76-125 µm	2	84	1	3	2	3	5	35
Charcoal 125+ µm		70		2			3	14

Table 6. Dog Hill cultivation phase AMS dates

Depth	Material	Lab number	Uncal. yr BP	Cal yr BC
302.0 cm	Peat	SUERC-39884	5405±30	BC 4338 – 4176
305.0 cm	Peat	SUERC-39883	5420±30	BC 4339 – 4237